Title: Stochastic representations of model uncertainties in the IFS

Authors: Martin Leutbecher, Pirkka Ollinaho, Sarah-Jane Lock, Simon Lang, Peter Bechtold, Anton Beljaars, Alessio Bozzo, Richard Forbes, Thomas Haiden, Robin Hogan and Irina Sandu

The operational ensemble forecasts at ECMWF use the stochastic schemes SPPT and SKEB to represent model uncertainties. The talk describes the configuration of these schemes at ECMWF and shows the impact of the schemes on ensemble spread and probabilistic skill. Relative to an ensemble forecast with initial perturbations only, SPPT increases the ensemble spread considerably up to about 3 weeks in the extra-tropics and beyond 4 weeks in the tropics. The additional spread generated by SKEB is quite moderate. The representation of model uncertainties with SPPT+SKEB leads to statistically significant reductions of the continuous ranked probability score and even more pronounced reductions of the logarithmic score.

While SPPT is efficient in generating ensemble spread, it is recognised that its current formulation lacks physical consistency in several ways: (i) there are no flux perturbations at the top of the atmosphere and the surface that are physically consistent with the tendency perturbation in the atmospheric column; (ii) SPPT does not conserve water; (iii) SPPT includes ad-hoc elements like tapering in the boundary layer or stratosphere; (iv) SPPT is unable to represent multi-variate aspects of uncertainties, for instance it cannot alter the shape of the heating profile due to convection.

Progress towards the development of a new model uncertainty representation at the process-level is also reported. A stochastic scheme embedded within the IFS physics has been developed that introduces local stochastic perturbations of parameters and variables. The new scheme is referred to as the Stochastically Perturbed Parametrisation scheme (SPP). Through its formulation it maintains physical consistency in the perturbations and addresses the points (i)-(iv) mentioned above. SPP targets uncertainties that are known to matter based on the experience of the scientists working on the parameterisation of individual processes. SPP, like SPPT, converges to the deterministic IFS physics in the limit of vanishing variance. The current version of SPP can sample distributions for up to 20 different parameters and variables in the parameterisations of (a) turbulent diffusion and subgrid orographic drag, (b) radiation, (c) cloud and large-scale precipitation, and (d) convection. The development started from distributions with variances proposed by the scientists working on the parameterisations. Sensitivity experiments with modified variances informed decisions on adjusting the initial variance estimates. Among the tested variances, the best candidate configuration was selected based on increases in ensemble spread and more importantly the reduction of ensemble mean RMS error.

The different parameters and variables are sampled in SPP using independent random patterns with prescribed time and spatial decorrelation scales. The sensitivity to the decorrelation scales was tested. Among the scales tested, a configuration with decorrelation scales of 2000 km and 72 h resulted in the most skilful medium-range predictions. Both smaller scales (500 km and 6 h) as well as infinite scales (globally fixed perturbations) resulted in lower ensemble spread and also reduced probabilistic skill.

In order to better understand the different characteristics of SPPT and SPP, the tendency perturbations due to the two schemes have been compared. As expected, SPP generates considerable perturbations in the lowest model level in contrast to SPPT. In the free troposphere, the tendency perturbations of SPP appear to be more confined to localised regions than those of SPPT. Looking at area-averages, SPP generates about the same (less) variance in the tendencies perturbations than SPPT in the free troposphere in the tropics (in the extratropics) in the first hours of the forecast. However, at longer lead times, SPPT generates more variance in the tendencies everywhere except close to the surface.

The impact of SPP and SPPT on ensemble forecasts has been examined up to a lead time of 32 days. Compared to an experiment with initial perturbations only, both schemes significantly increase spread. The additional spread generated by SPP ranges between about 0.6 and 1.1 of the additional spread generated by SPPT depending on variable and region. SPP also leads to more skilful ensemble forecasts compared to the experiment with initial perturbations only. The reductions in CRPS due to SPP range between about 0.5 and 0.9 of the reductions in CRPS obtained with SPPT.

As part of the development of SPP, its impact on the model climate has been evaluated as well. Based on four 13 month integrations RMS errors of annual mean fields have been compared for runs with the unperturbed IFS model, with SPPT and with SPP. Relative to the run with the unperturbed model, the run with SPP consistently reduces RMS errors of the annual mean of a range of fields from tropical winds, precipitation, total column water vapour to top-of-the-atmosphere thermal radiation. SPPT also results in improvements of the climate but in a less consistent way. For instance, it clearly degrades total column water vapour. This is believed to be caused by its lack of humidity conservation.

The evaluation of SPP in the Ensemble of Data Assimilations (EDA) is ongoing. Like PPT, using SPP results in considerable additional spread in EDA analyses and EDA short-range forecasts. Preliminary results show that the additional spread introduced by SPP does not decrease towards the surface in the boundary layer as is the case with SPPT. In the free troposphere, the spread increase due to SPPT and due to SPP are of a similar order of magnitude.

Future extensions to the SPP scheme are envisaged that would address further uncertainties in (i) the vertical mixing above the boundary layer, (ii) the thermodynamic coupling between surface and atmosphere and (iii) trace gas sources. Future progress will also rely on process-oriented diagnostics of ensemble forecasts with the stochastic representation of model uncertainties.